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Progress report on archival tagging within the Papua New Guinea Tagging Program

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Introduction

The tagging of yellowfin and bigeye tuna in the Papua New Guinea Tagging Program (PNGTP) included the deployment of archival tags. These deployments were implemented to contribute to investigations on the connectivity of yellowfin tuna in the Coral Sea region of the western warm pool with fisheries within the Eastern Tuna and Billfish Fishery in Australia, in addition to contributing to the overall data collected and analyzed under the PTTP. The purpose of this research report is to provide an overview of the tag deployments and some preliminary analyses of recovered tags as part of analyses being conducted on archival tags data derived from the Pacific Tuna Tagging Program (PTTP). Priorities for more focused data analyses to be conducted during the coming 12 months will be presented. It should be noted that formal analyses of the data provided by the archival tags detailed here has not yet been undertaken by the project team. As a result any formal analyses of data provided by the archival tags may not reflect or incorporate the preliminary analyses presented here and subsequent results may not reflect or incorporate the results presented here. The contents of this paper are not to be referred to or cited in any way without the express written permission from each of CSIRO, SPC and NFA.

Tag deployments

A total of 64 archival tags (LAT2810, Lotek Wireless, St Johns) were deployed in yellowfin tuna and one in bigeye tuna during PNGTP operations in the Solomon Sea in April 2011, January 2012 and April 2013 (Table 1, Figure 1). A further 4 archival tags were deployed in yellowfin in May and June in 2011and 11 archival tags deployed in bigeye tuna in March 2012 in the Bismark Sea/northern Papua New Guinea Exclusive Economic Zone (PNG EEZ) (Table 1, Figure 1).

Once captured and brought on board the fishing vessel, each fish was measured (length to caudal fork in cm) and an archival tag surgically implanted in the peritoneal cavity of the fish (as per details provided in WCPFC-SC03-BI-WP-04). Pressure (depth), internal body temperature, external temperature and ambient light were measured and logged at 10 second intervals (for the Solomon Sea deployments) and 30 second intervals (for the Bismark Sea/northern EEZ deployments) and stored in the tags flash memory. Each fish was also tagged with an orange conventional plastic dart tag to aid in alerting fishers, processors and observers to the presence of an archival tag on recapture. Sizes of yellowfin tuna tagged in the Solomon Sea were 49 – 81 cm LCF with the bigeye tuna tagged in this region 65 cm LCF in size (Figure 1). Sizes of yellowfin tuna tagged in the Bismark Sea/northern PNG EEZ were 52 – 55 cm and bigeye tuna 50 – 67 cm (Figure 1).

Table 1. PNGTP archival tag release and recovery numbers per species and area (recovered positions verified).

Release area	Species	No. releases	No. recoveries	Recovered area					
				Bismarck	Nth EEZ	East EEZ	Solomon sea	Outside PNG	Unknown
Bismarck Sea/ Northern EEZ	YFT	4	1	0	0	0	0	1	0
	BET	11	7	0	6	0	0	1	0
Solomon Sea	YFT	64	16	6	0	1	2	5	2
	BET	1	0	0	0	0	0	0	0

A total of 24 tags (17 yellowfin tuna, seven bigeye tuna) have been reported to be recaptured to date (Table 1). Tag deployments for yellowfin ranged 30 – 1061[1] days at liberty, with full records of data able to be downloaded from eleven tags and partial data records from two tags. One tag failed, one tag was recovered, but not returned, one tag is currently being interrogated by the tag manufacturer for possible data retrieval, and one tag is currently in the process of being returned to the project team. Accurate recapture dates and/or locations were not provided for five tags. Of the 12 tags from which data were able to be recovered, two have erroneous light sensor data; the remaining tags have each provided 36 – 329 days of depth, external temperature, internal temperature and ambient light data.

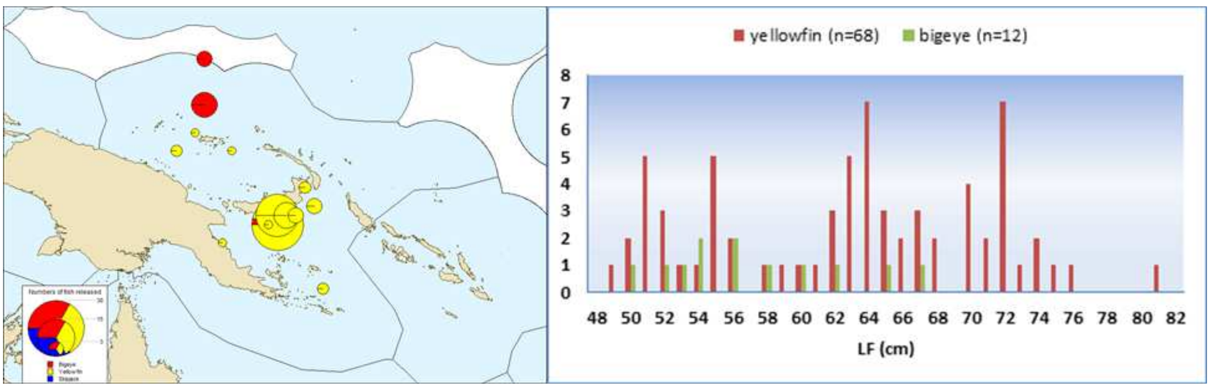

Figure 1. The distribution of archival tag releases (left) and sizes of fish tagged (right) per species during PNGTP cruises.

[1] The 1061 days at liberty is yet to be confirmed as the tag is currently with the tag manufacturer being interrogated for data retrieval.

Of tags released in bigeye tuna, seven have been reported to be recaptured to date. Six bigeye were recaptured after only two days at liberty and the seventh tag failed after 19 days. No accurate recapture date and location details are available for this tag.

Data analyses

Horizontal movement

Preliminary estimates of the horizontal movements of yellowfin tuna derived from light data recorded by recovered tags was undertaken using the R-package Trackit (R version 3.0.2) as a first visualization of broad patterns of displacement. Removal of records where light records were spurious was undertaken by visual inspection. When spurious light records were detected the light readings for the entire day were removed. The location of release and recapture of the tag were fixed variables. If model convergence was not achieved using default parameter settings, individual parameters were adjusted in turn until all parameters were estimated and convergence was achieved. Because the model requires a fixed recapture data and location to constrain position estimation, the package could only be run on light data from tags for which a recapture position was provided or could be verified. We have not undertaken any preliminary analysis of the tags deployed in the Bismarck Sea due to the short deployment/data period of the majority of tags.

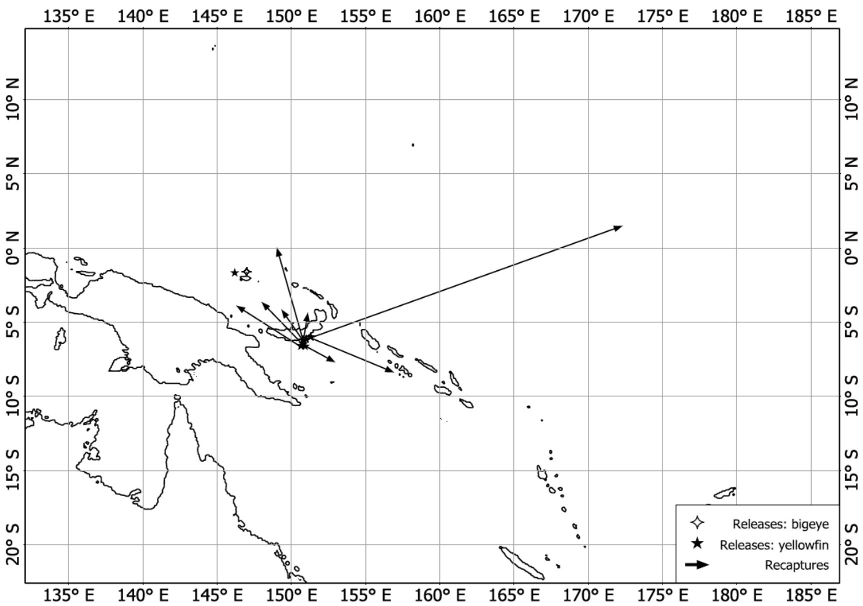

Figure 2. Release and recapture positions of yellowfin and bigeye tuna tagged in the Solomon and Bismarck Seas.

Displacements of fish between release and recapture positions ranged 112 – 2748 km, reflecting a mixture of short and long distance movements (Figure 2). Time at liberty did not reflect displacement distance (Figure 3). The current number of recovered tags is insufficient to evaluate relationships between displacement and fish size (Figure 3).

Preliminary observations of daily positions from light data provided by the tags released in the Solomon Sea (Figure 4) provide some correspondence with the general pattern of recoveries from the conventional tags also released in the same area. Few conventional tags have been recovered in the eastern sector of the PNG EEZ despite considerable fishing effort in this area (Figure 5). Initial exploration of the estimated movements of these yellowfin tuna also suggests lower rates of movement into this sector. It should be noted firstly, that datasets derived from archival tag returns to date are small and secondly, that position estimation is imprecise (the uncertainties associated with position estimates are not presented in Figure 4, but can be on the order of several degrees) and as a result these preliminary estimates of movement should be viewed cautiously.

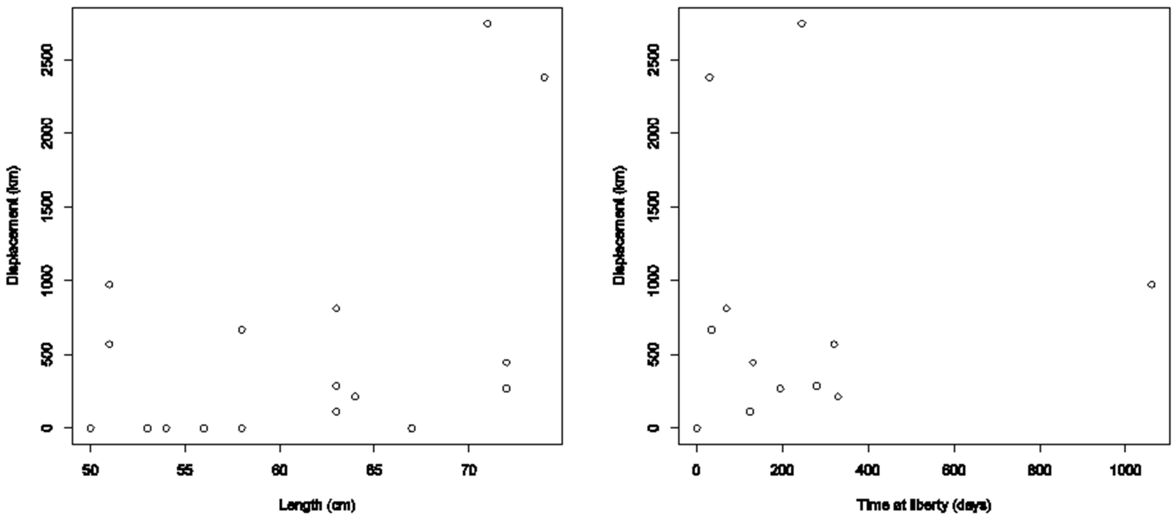

Figure 3. Displacement of archival tags deployed in in yellowfin tuna tagged in the Solomon Sea in relation to fish length (left) and time at liberty (right).

Vertical movement

As an initial exploration of the vertical behaviour of the data collected from yellowfin tuna presented here, a Hidden Markov model (HMM) incorporating multivariate behavioural-state distributions based on summarised depth and water temperature data as detailed in Scutt Phillips et al. (2013) and based on Patterson et al. (In Press) was applied to archival tags data from tags recovered from yellowfin tuna. Two fish were excluded from the analysis (tags 0871 and 0866), due to extended gaps from corrupted data in the time-series.

In order to reduce the voluminous nature of data derived from archival tags thermal habitat (water temperature) and vertical movement (depth) data were summarised into three-hour intervals (mean water temperature and mean step length). Mean step length defined as the depth travelled in one direction before changing direction, and can be considered a proxy for amplitude in vertical movement. Summarisation of data at this time interval was based on previous exploratory analyses of yellowfin and bigeye tuna vertical behaviour from archival tags deployed as part of the PTTP (Scutt Phillips et al. 2013). Future analyses using this modelling method on a broader dataset derived from the PTTP (and incorporating these tags) will explore varying temporal intervals to ascertain optimal summarisation intervals across spatial regions and size classes.

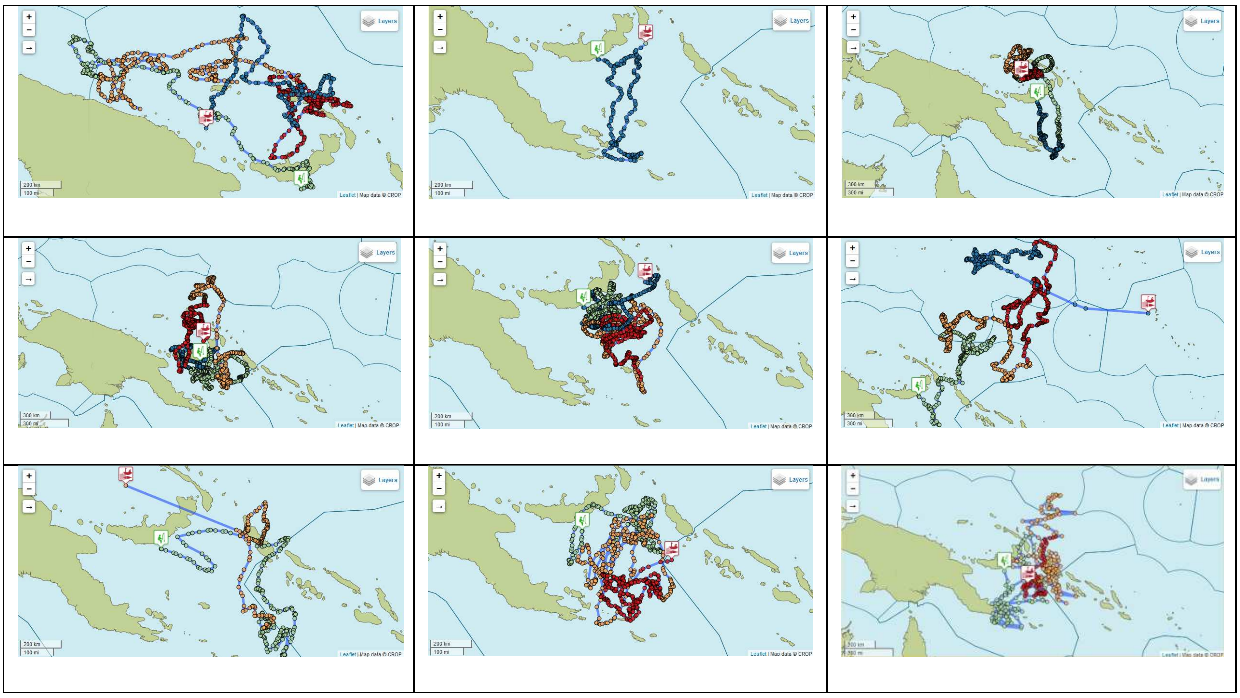

Figure 4 Examples of most probable track estimates from light data derived from archival tags deployed in yellowfin tuna tagged in the Solomon Sea.

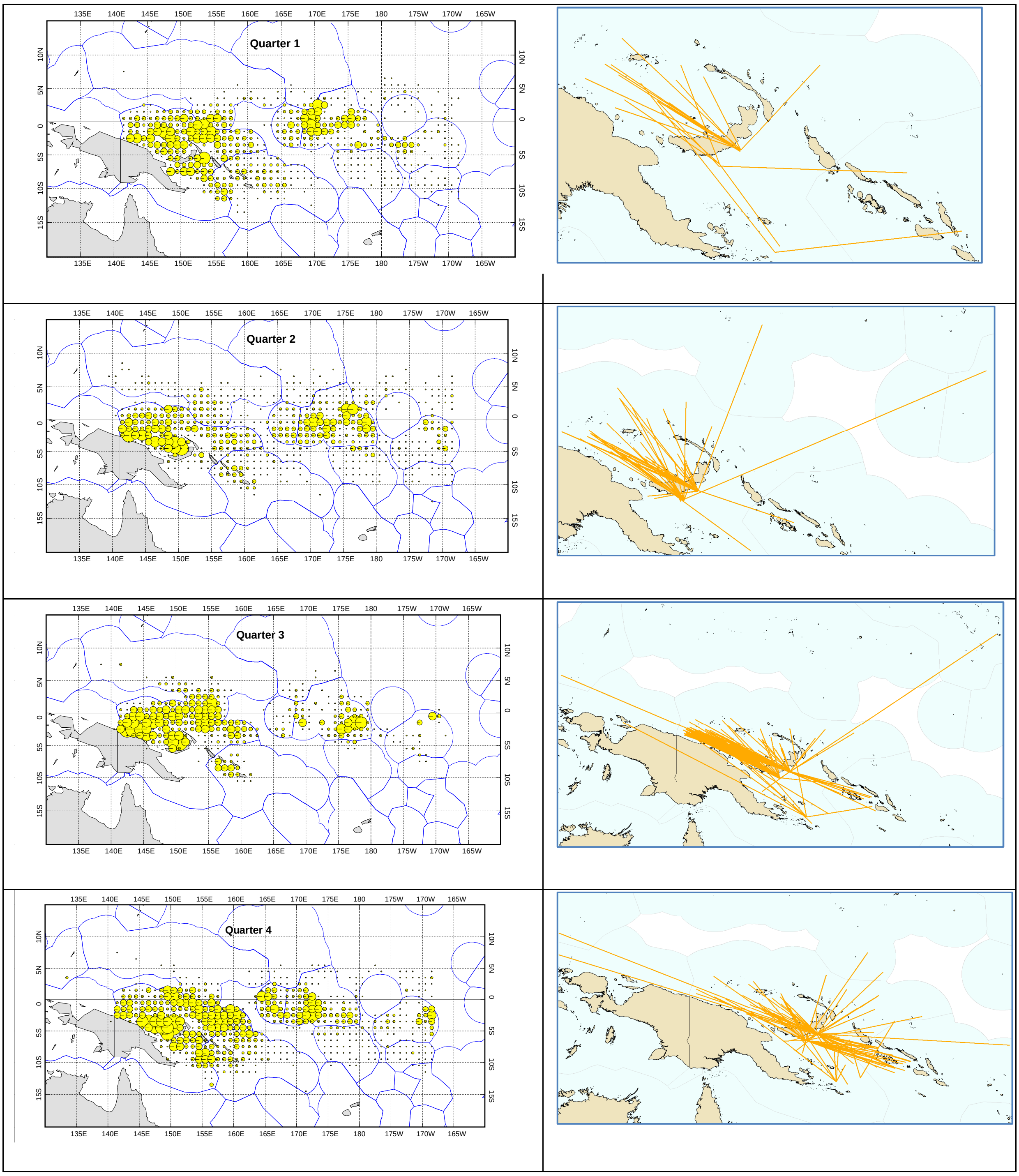

Figure 5. Yellowfin tuna catches by purse seine vessels per quarter between 2011 and 2013 (left) and displacements of yellowfin tuna tagged with conventional tags under the PNGTP per quarter.

We used the HMM to classify the summarised time-series of each individual into two behavioural states with each state described by a multivariate distribution of the two summary metrics. After classification we named each state as either relatively shallow or relatively deep based on higher or lower values of the distribution centre in the water temperature dimension. We assumed colder water suggests deeper habitat. Length of fish was included as a covariate in the model to explore the potential for the influence of size on behaviour. An extra covariate parameter was estimated to allow length to linearly effect state distribution means during the time at liberty. Although length at recapture is usually returned during tag recovery, this information is not always available or reliable. As an alternative, we took the length at release and projected growth forward through time using the growth models for yellowfin tuna in recent stock assessments (Langley et al. 2011). To visualize vertical behaviour classifications in relation to horizontal movements, estimates of daily positions derived from the trackit package were colour coded to reflect the probability of each individual of being in a shallow state as estimated by the HMM over a 24 hour period.

Shallow state behaviour as estimated by the HMM were associated with water temperatures of 28 - 29°C (Figure 6). Shallow behaviours were very similar across all the individual fish, with differences mainly in the amplitude of movement through the water column. Vertical behaviour associated with classification by the model as being in a deeper state varied between individuals. These deep state behaviours as estimated by the HMM were associated with water temperatures of 22.4 - 27.4°C (Figure 6). The vertical movements of one fish were such that classification into the two behavioural states was unable to be estimated by the model. There was little qualitative evidence of changes in thermal habitat in association with fish length across either state (Figure 7). It should be noted that sample sizes of individuals investigated were small and so the preliminary results presented here may not be reflective of the broader population. Further investigation of the thermal habitats associated with vertical movements and the potential influence of size on vertical behaviour will be investigated more broadly as part of the analyses of the larger archival tag dataset collected by the PTTP. Investigation of a larger dataset will also allow incorporation of reliable length at recapture measurements to be used as a covariate rather than lengths estimated from growth models.

Extended periods of shallow behaviour, which has been assumed to be reflective of island or floating object association, varied considerably among individuals, with some fish exhibiting fewer but longer periods in a shallow state, while others exhibited more frequent but shorter periods in a shallow state (Figure 8). Similarly, spatial occurrence of surfacing behaviour varied considerably (Figure 9).

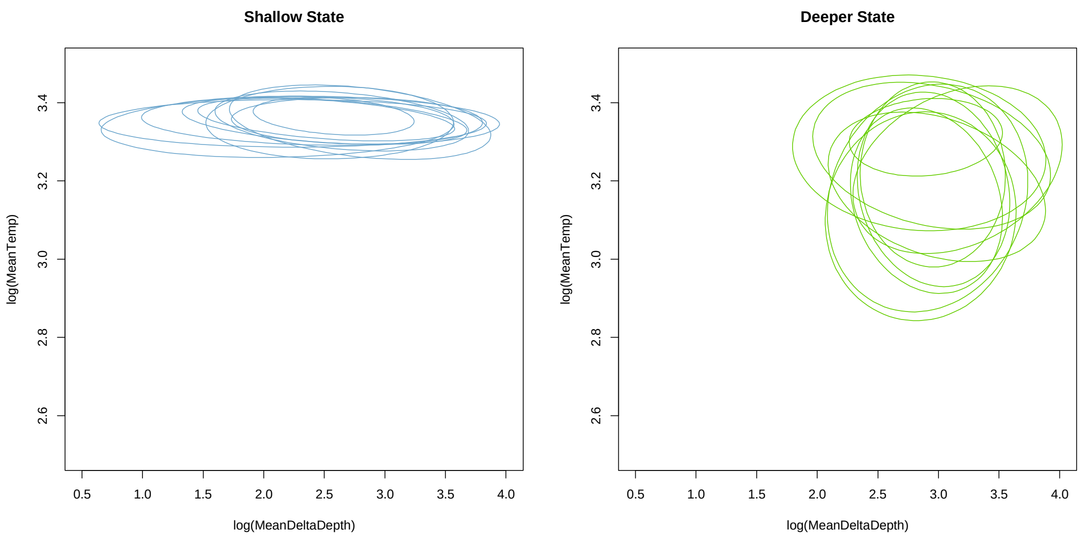

Figure 6. Estimated behavioural state distributions for yellowfin tuna tagged with archival tags in the Solomon Sea. States are shown as 95% confidence multivariate distributions in log-transformed mean step length – mean water temperature space.

Future priorities for data analyses

Analyses of data from archival tag deployments will focus on the priorities for the two purposes under which these tags were deployed: (i) investigations of the connectivity of yellowfin tuna in the Coral Sea region of the western warm pool with fisheries within the Eastern Tuna and Billfish Fishery in Australia and (ii) investigations of yellowfin and bigeye tuna horizontal and vertical movements as part of the PTTP. It should be noted that the priorities associated with each of these may vary to some extent as further data become available from additional recaptures and science questions and management needs (both at the national and regional level) might be modified.

Estimation of the horizontal movements from light data derived from the archival tags recovered used the package trackit. While the model used in this package provides a substantive advance on previous geolocation methods, it is problematic in a number of ways. First, while in theory this method allows for the inclusion of ancillary data such as SST, in practice incorporating these data into the state-space model used to estimate daily positions in the package leads to many instances where the model does not converge to a viable solution. Second, this method does not include a land mask. This results in spurious position estimation which places individuals on land. Third, the method is based on an assumption of normal (Gaussian) errors and an assumed structure for autocorrelation in the data. Assumption of structure for autocorrelation are likely to contribute to the practical difficulties in getting the model to converge. Finally, the method already assumes a movement model (i.e. the process model) in filtering a track. This is unlikely to be a problem when track estimation is the sole output required, but if for example, the focus of analyses is to develop modelling approaches where different types of behaviour might be related to covariates (e.g. environmental, physiological), then this approach is not ideal. Further, because trackit uses raw light data (rather than depth corrected light data) derived from archival tags any diving behavior exhibited by the tagged individual impacts on the quality of light data input into the method and overall position estimation, increasing the error associated with position estimates.

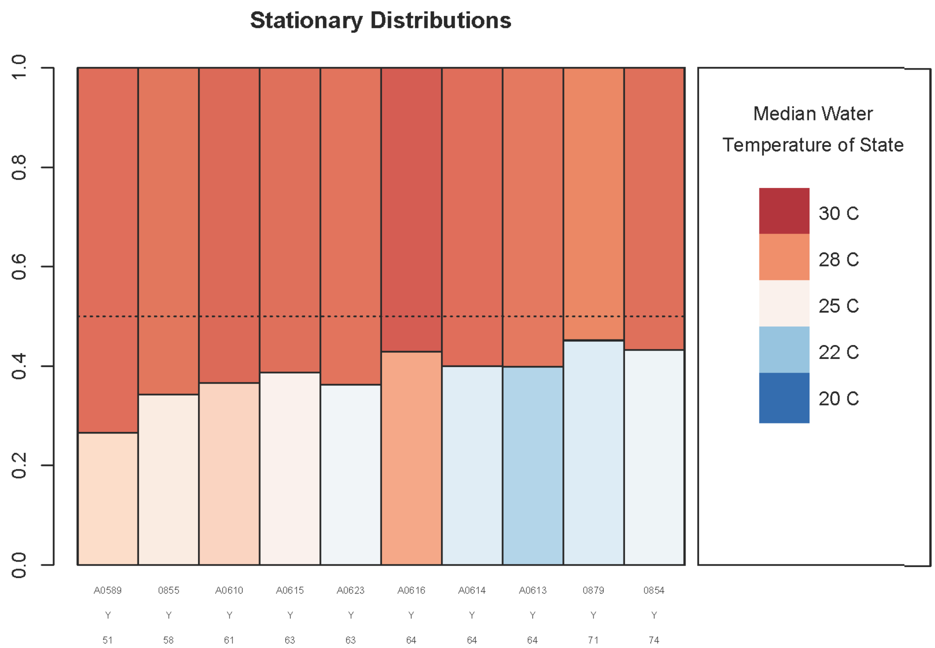

Figure 7. Estimated proportion of time spent in each of the two behavioural states as defined in the HMM for each yellowfin tuna tagged in the Solomon Sea if the time-series continued on indefinitely. Bars are coloured by the value of the state-distribution centre in the mean temperature dimension.

Future estimation of horizontal movements will utilize methods currently being developed which allow for light data to firstly be corrected for time varying depth attenuation within a statistical framework and secondly, for the likelihood of a candidate position to be calculated. Position estimates are statistically filtered using a state-space methods which allow auxiliary data such as SST and bathymetry to be incorporated (e.g. Pedersen et al. 2011). Use of this method will largely overcome the problems identified with the use of the package trackit and provide more robust positions estimates and error distributions which can be investigated in relation to covariates such as ocean temperature, primary productivity, fish length or distribution of fishing fleets (e.g. Patterson et al. 2009). Habitat modelling approaches currently being developed can then be used to explore relationships with environmental covariates and behavioural modelling approaches can be used to explore relationships with environmental and physiological covariates.

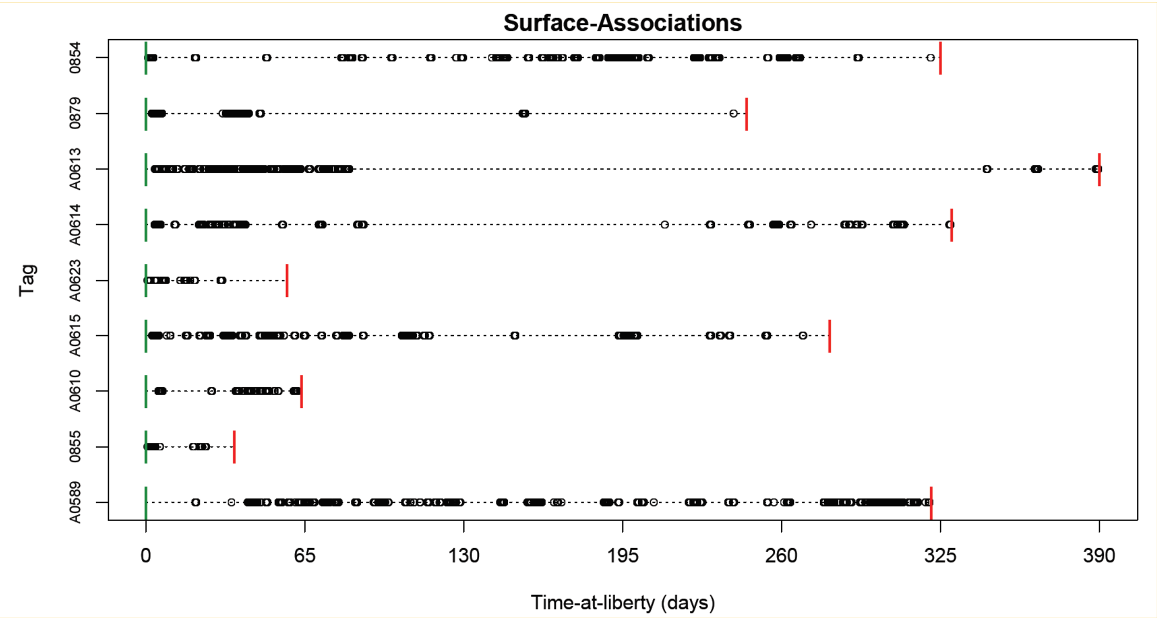

Figure 8. Identified periods where the probability of being in a shallow state is above 90% over a 24-hour period. Release and recapture points are marked for each fish in green and red, respectively.

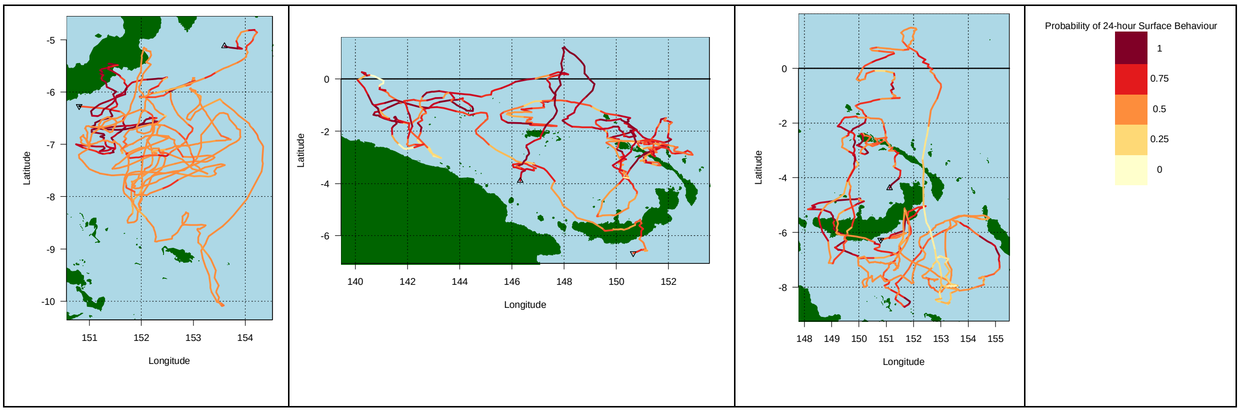

Figure 9. Estimated horizontal movements of yellowfin tuna tagged in the Solomon Sea along which the mean probability of being in an extended shallow state in a 24 hour period has been superimposed.

Acknowledgments

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References

Langley A, Hoyle S, Hampton J. 2011. Stock assessment of yellowfin tuna in the western and central Pacific Ocean (Rev.1 - 03August2011). SA-WP-03. 7th Regular Session of the Scientific Committee of the western and Central Pacific Fisheries Commission.

Patterson TA, Basson M, Bravington MV, Gunn JS. 2009. Classifying movement behavior in relation to environmental conditions using hidden Markov models. Journal of Animal Ecology 78: 1113 – 1123.

Patterson TA, Bravington MV, Westcott M, Evans K. In Press. Analysing vertical movements from archival tags using Hidden Markov Models: addressing non-linearity, differential behavioural time-scales and data volume. Fisheries Oceanography.

Pedersen MW, Patterson TA, Thygesen UH, Madsen H. 2011. Estimating animal behavior and residency from movement data. Oikos 120: 1281 – 1290.

Scutt-Phillips J, Patterson T, Pilling G, Hoyle S, Leroy B, Nicol S. 2013. Species Specific Vertical Habitat Utilisation by Tunas in the Tropical WCPO. RP-PTTP-03. 9th Regular

Session of the Scientific Committee of the western and Central Pacific Fisheries Commission.